

purposes of this method, be used in a two-dimensional mode (i.e., measuring yaw angle, but not pitch angle). When the 3-D probe is used as a 2-D probe, only the velocity pressure and yaw-null pressure are obtained using the pressure taps referred to as P_1 , P_2 , and P_3 . The differential pressure P_1-P_2 is a function of total velocity and corresponds to the ΔP obtained using the Type S probe. The differential pressure P_2-P_3 is used to yaw null the probe and determine the yaw angle. The differential pressure P_4-P_5 , which is a function of pitch angle, is not measured when the 3-D probe is used in 2-D mode.

6.1.3 Other probes. [Reserved]

6.1.4 Probe sheath. The probe shaft shall include an outer sheath to: (1) provide a surface for inscribing a permanent reference scribe line, (2) accommodate attachment of an angle-measuring device to the probe shaft, and (3) facilitate precise rotational movement of the probe for determining yaw angles. The sheath shall be rigidly attached to the probe assembly and shall enclose all pressure lines from the probe head to the farthest position away from the probe head where an angle-measuring device may be attached during use in the field. The sheath of the fully assembled probe shall be sufficiently rigid and straight at all rotational positions such that, when one end of the probe shaft is held in a horizontal position, the fully extended probe meets the horizontal straightness specifications indicated in section 8.2 below.

6.1.5 Scribe lines.

6.1.5.1 Reference scribe line. A permanent line, no greater than 1.6 mm (1/16 in.) in width, shall be inscribed on each manual probe that will be used to determine yaw angles of flow. This line shall be placed on the main probe sheath in accordance with the procedures described in section 10.4 and is used as a reference position for installation of the yaw angle-measuring device on the probe. At the discretion of the tester, the scribe line may be a single line segment placed at a particular position on the probe sheath (e.g., near the probe head), multiple line segments placed at various locations along the length of the probe sheath (e.g., at every position where a yaw angle-measuring device may be mounted), or a single continuous line extending along the full length of the probe sheath.

6.1.5.2 Scribe line on probe extensions. A permanent line may also be inscribed on any probe extension that will be attached to the main probe in performing field testing. This allows a yaw angle-measuring device mounted on the extension to be readily aligned with the reference scribe line on the main probe sheath.

6.1.5.3 Alignment specifications. This specification shall be met separately, using the procedures in section 10.4.1, on the main probe and on each probe extension. The rota-

tional position of the scribe line or scribe line segments on the main probe or any probe extension must not vary by more than 2° . That is, the difference between the minimum and maximum of all of the rotational angles that are measured along the full length of the main probe or the probe extension must not exceed 2° .

6.1.6 Probe and system characteristics to ensure horizontal stability.

6.1.6.1 For manual probes, it is recommended that the effective length of the probe (coupled with a probe extension, if necessary) be at least 0.9 m (3 ft.) longer than the farthest traverse point mark on the probe shaft away from the probe head. The operator should maintain the probe's horizontal stability when it is fully inserted into the stack or duct. If a shorter probe is used, the probe should be inserted through a bushing sleeve, similar to the one shown in Figure 2G-3, that is installed on the test port; such a bushing shall fit snugly around the probe and be secured to the stack or duct entry port in such a manner as to maintain the probe's horizontal stability when fully inserted into the stack or duct.

6.1.6.2 An automated system that includes an external probe casing with a transport system shall have a mechanism for maintaining horizontal stability comparable to that obtained by manual probes following the provisions of this method. The automated probe assembly shall also be constructed to maintain the alignment and position of the pressure ports during sampling at each traverse point. The design of the probe casing and transport system shall allow the probe to be removed from the stack or duct and checked through direct physical measurement for angular position and insertion depth.

6.1.7 The tubing that is used to connect the probe and the pressure-measuring device should have an inside diameter of at least 3.2 mm ($\frac{1}{8}$ in.), to reduce the time required for pressure equilibration, and should be as short as practicable.

6.1.8 If a detachable probe head without a sheath [e.g., a pitot tube, typically 15.2 to 30.5 cm (6 to 12 in.) in length] is coupled with a probe sheath and calibrated in a wind tunnel in accordance with the yaw angle calibration procedure in section 10.5, the probe head shall remain attached to the probe sheath during field testing in the same configuration and orientation as calibrated. Once the detachable probe head is uncoupled or re-oriented, the yaw angle calibration of the probe is no longer valid and must be repeated before using the probe in subsequent field tests.

6.2 Yaw Angle-measuring Device. One of the following devices shall be used for measurement of the yaw angle of flow.

6.2.1 Digital inclinometer. This refers to a digital device capable of measuring and displaying the rotational position of the probe to within $\pm 1^\circ$. The device shall be able to be locked into position on the probe sheath or probe extension, so that it indicates the probe's rotational position throughout the test. A rotational position collar block that can be attached to the probe sheath (similar to the collar shown in Figure 2G-4) may be required to lock the digital inclinometer into position on the probe sheath.

6.2.2 Protractor wheel and pointer assembly. This apparatus, similar to that shown in Figure 2G-5, consists of the following components.

6.2.2.1 A protractor wheel that can be attached to a port opening and set in a fixed rotational position to indicate the yaw angle position of the probe's scribe line relative to the longitudinal axis of the stack or duct. The protractor wheel must have a measurement ring on its face that is no less than 17.8 cm (7 in.) in diameter, shall be able to be rotated to any angle and then locked into position on the stack or duct test port, and shall indicate angles to a resolution of 1° .

6.2.2.2 A pointer assembly that includes an indicator needle mounted on a collar that can slide over the probe sheath and be locked into a fixed rotational position on the probe sheath. The pointer needle shall be of sufficient length, rigidity, and sharpness to allow the tester to determine the probe's angular position to within 1° from the markings on the protractor wheel. Corresponding to the position of the pointer, the collar must have a scribe line to be used in aligning the pointer with the scribe line on the probe sheath.

6.2.3 Other yaw angle-measuring devices. Other angle-measuring devices with a manufacturer's specified precision of 1° or better may be used, if approved by the Administrator.

6.3 Probe Supports and Stabilization Devices. When probes are used for determining flow angles, the probe head should be kept in a stable horizontal position. For probes longer than 3.0 m (10 ft.), the section of the probe that extends outside the test port shall be secured. Three alternative devices are suggested for maintaining the horizontal position and stability of the probe shaft during flow angle determinations and velocity pressure measurements: (1) monorails installed above each port, (2) probe stands on which the probe shaft may be rested, or (3) bushing sleeves of sufficient length secured to the test ports to maintain probes in a horizontal position. Comparable provisions shall be made to ensure that automated systems maintain the horizontal position of the probe in the stack or duct. The physical characteristics of each test platform may dictate the most suitable type of stabilization device. Thus, the choice of a specific stabilization device is left to the judgement of the testers.

6.4 Differential Pressure Gauges. The velocity pressure (ΔP) measuring devices used during wind tunnel calibrations and field testing shall be either electronic manometers (e.g., pressure transducers), fluid manometers, or mechanical pressure gauges (e.g., Magnehelic Δ gauges). Use of electronic manometers is recommended. Under low velocity conditions, use of electronic manometers may be necessary to obtain acceptable measurements.

6.4.1 Differential pressure-measuring device. This refers to a device capable of measuring pressure differentials and having a readability of ± 1 percent of full scale. The device shall be capable of accurately measuring the maximum expected pressure differential. Such devices are used to determine the following pressure measurements: velocity pressure, static pressure, and yaw-null pressure. For an inclined-vertical manometer, the readability specification of ± 1 percent shall be met separately using the respective full-scale upper limits of the inclined anvertical portions of the scales. To the extent practicable, the device shall be selected such that most of the pressure readings are between 10 and 90 percent of the device's full-scale measurement range (as defined in section 3.4). In addition, pressure-measuring devices should be selected such that the zero does not drift by more than 5 percent of the average expected pressure readings to be encountered during the field test. This is particularly important under low pressure conditions.

6.4.2 Gauge used for yaw nulling. The differential pressure-measuring device chosen for yaw nulling the probe during the wind tunnel calibrations and field testing shall be bi-directional, i.e., capable of reading both positive and negative differential pressures. If a mechanical, bi-directional pressure gauge is chosen, it shall have a full-scale range no greater than 2.6 cm (i.e., -1.3 to $+1.3$ cm) [1 in. H_2O (i.e., -0.5 in. to $+0.5$ in.)].

6.4.3 Devices for calibrating differential pressure-measuring devices. A precision manometer (e.g., a U-tube, inclined, or inclined-vertical manometer, or micromanometer) or NIST (National Institute of Standards and Technology) traceable pressure source shall be used for calibrating differential pressure-measuring devices. The device shall be maintained under laboratory conditions or in a similar protected environment (e.g., a climate-controlled trailer). It shall not be used in field tests. The precision manometer shall have a scale gradation of 0.3 mm H_2O (0.01 in. H_2O), or less, in the range of 0 to 5.1 cm H_2O (0 to 2 in. H_2O) and 2.5 mm H_2O (0.1 in. H_2O), or less, in the range of 5.1 to 25.4 cm H_2O (2 to 10 in. H_2O). The manometer shall have manufacturer's documentation that it meets an accuracy specification of at least 0.5 percent of full scale. The NIST-traceable pressure source shall be recertified annually.